Geomagnetically Induced Currents

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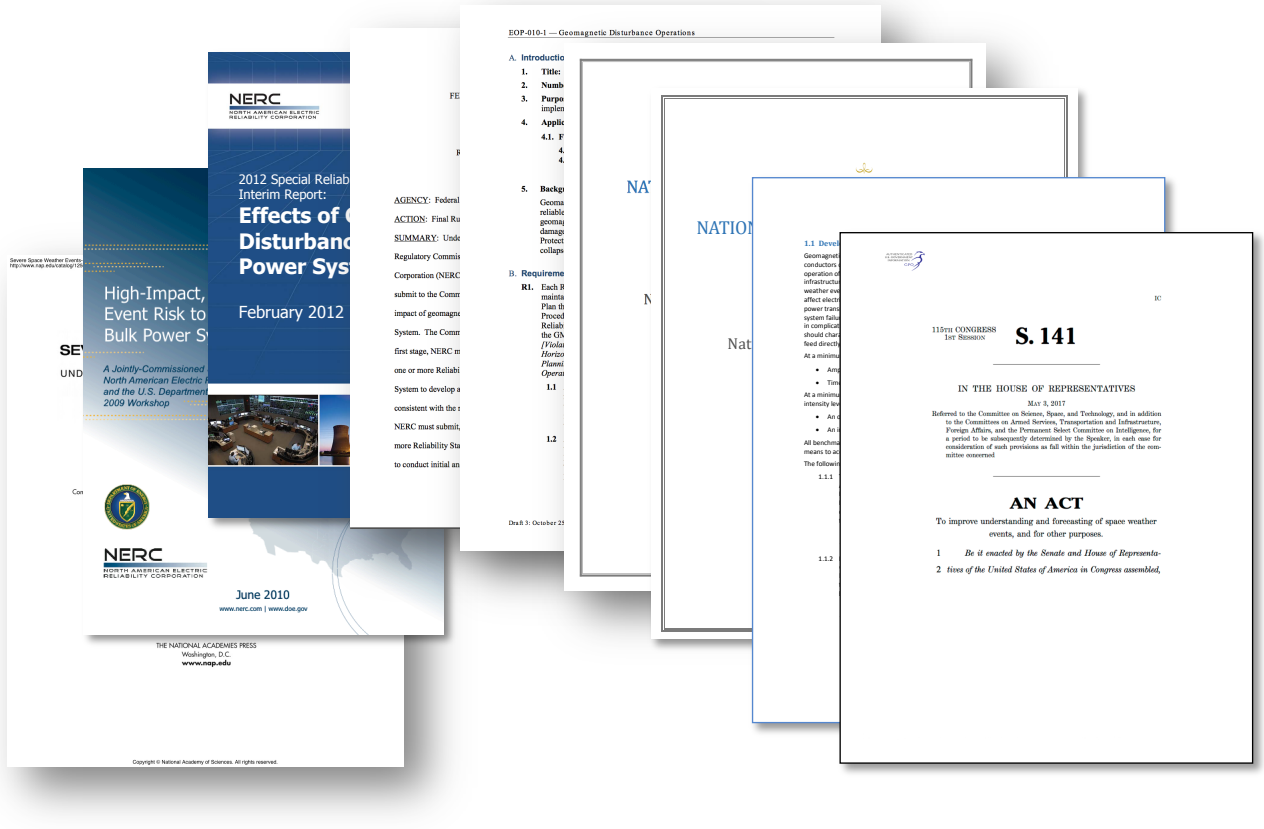
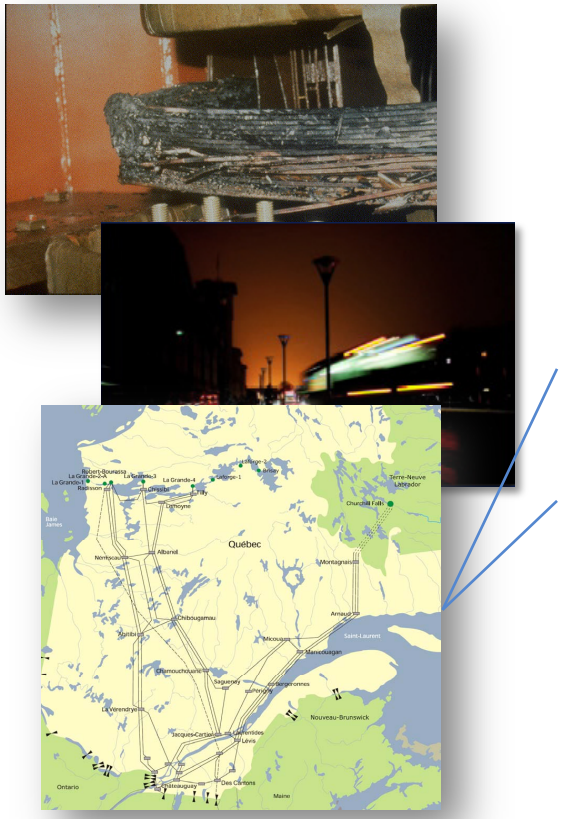
- Why do we care?
- Physics of geomagnetically induced currents (GIC).
- GIC systems science.
- Extreme GIC and E-field scenarios.
- NASA GSFC work on the topic.
- Conclusions.

Brief history of the high-level US interest in the topic



Why do we care?



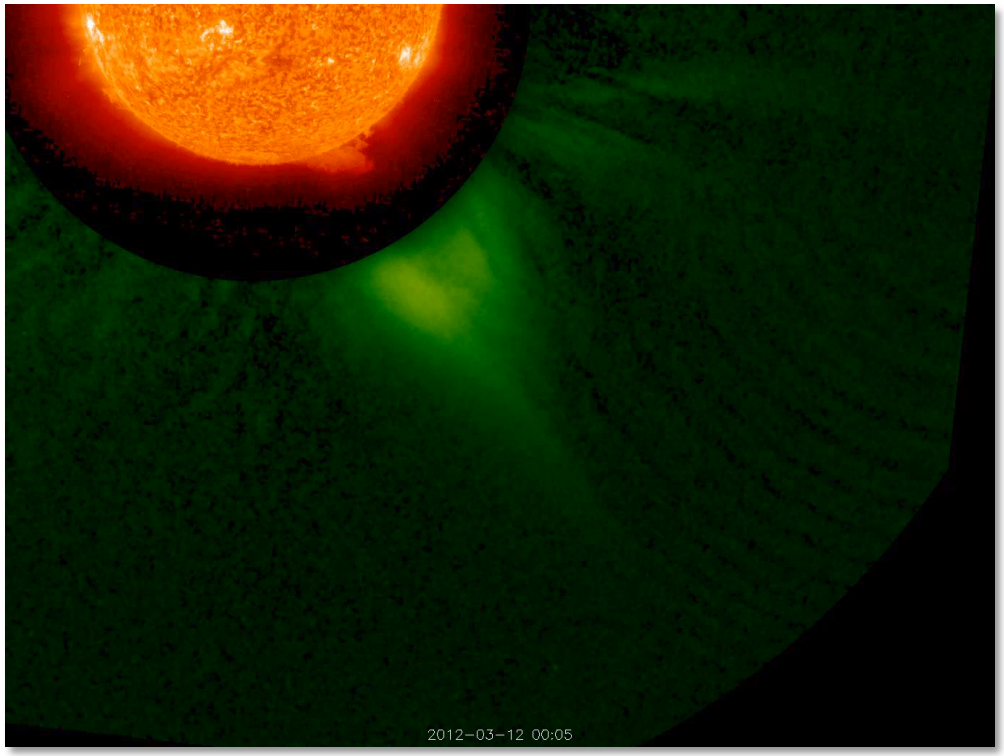
Hydro-Québec March 1989

GIC-driven half-cycle saturation of power transformers can cause:

- Leakage magnetic fields.
  → Transformer heating
- Harmonic currents.
  → Relay tripping
- Increased reactive power consumption.
  → Voltage instability

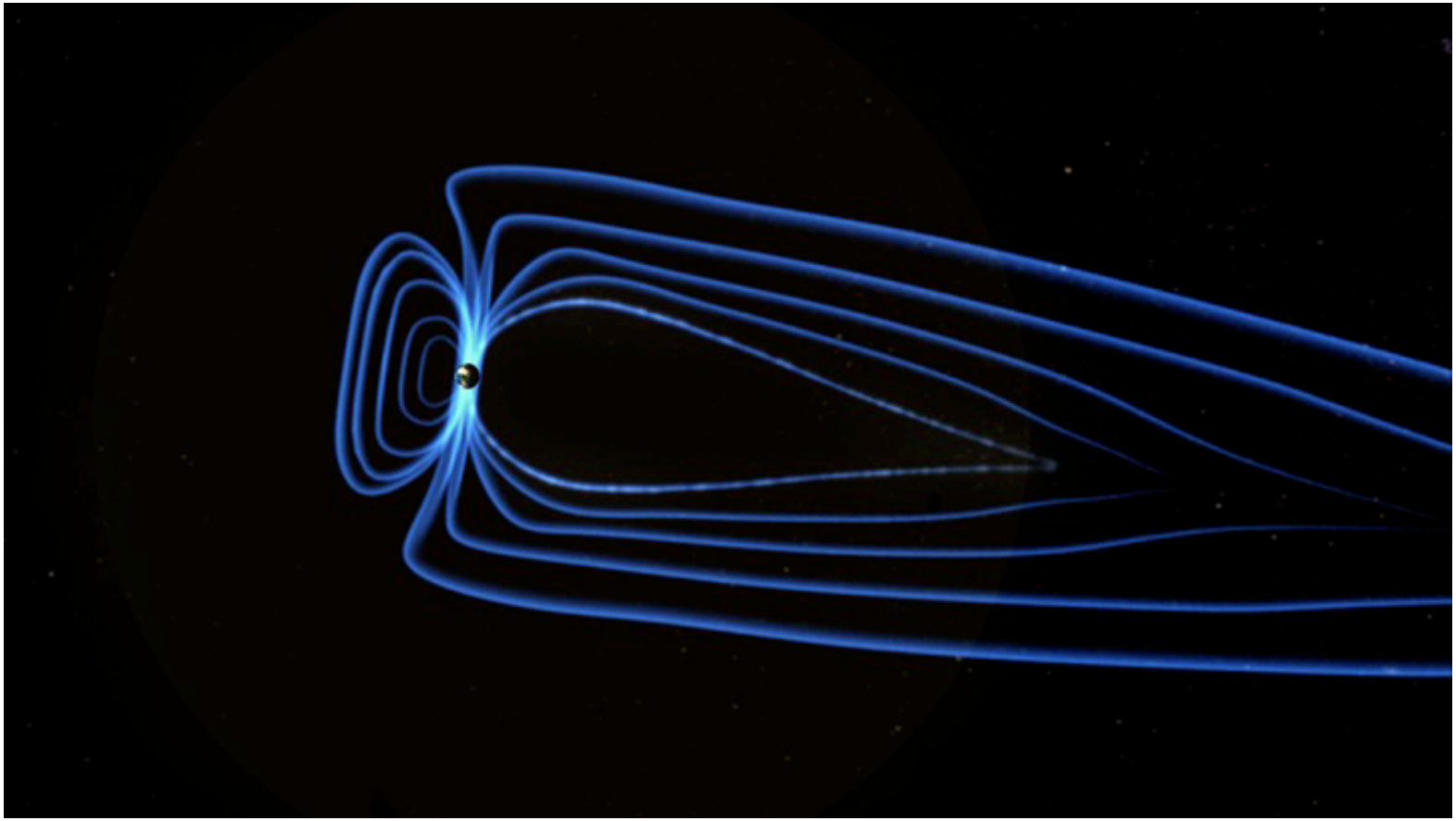
Physics of GIC

Many large solar eruptions are associated with *coronal mass ejections* (CMEs) releasing 10^{12}-10^{13} kg of solar corona material at speeds of 200-3000 km/s. CMEs drive the most significant geomagnetic activity and GIC.



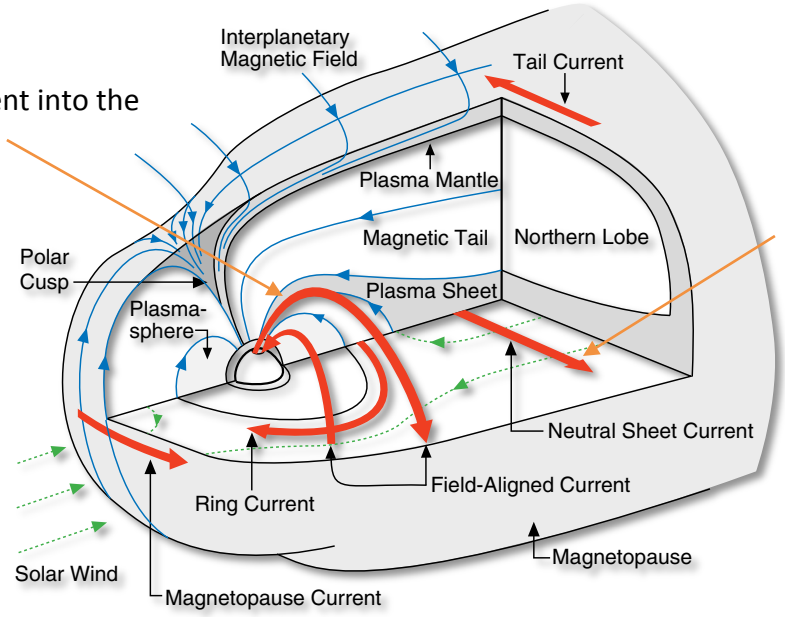
STEREO B 304 Angstrom EUV and white light coronagraph March 12, 2012

Physics of GIC



Physics of GIC

≈ 1 MA current into the ionosphere

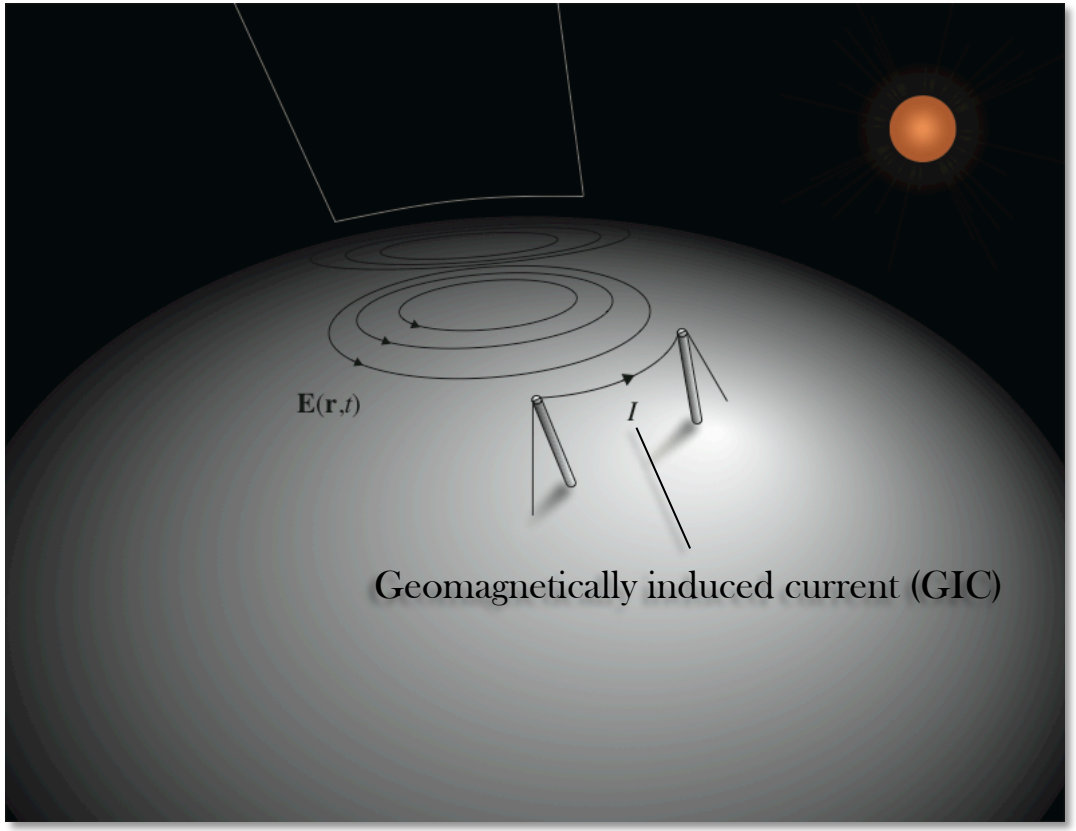


Which powers electric currents in the system that generate the ground magnetic field variations

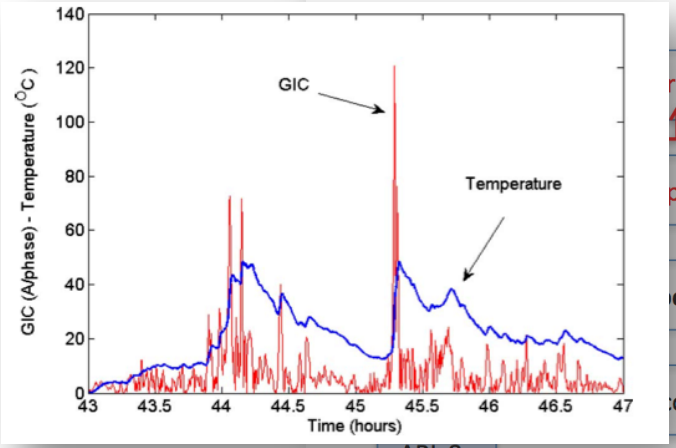
0.1-10 TW of power going in

Russell (IEEE Trans. on Plasma Science, 2000)

Physics of GIC



The GIC systems science



Marti et al. (2013)

Pulkkinen et al. (2017)

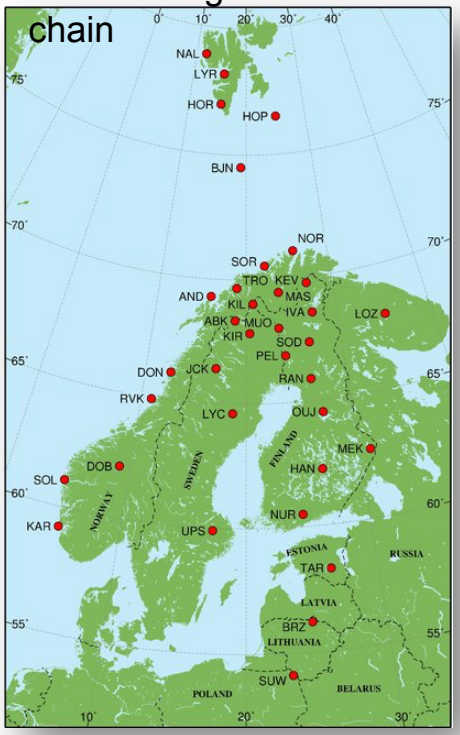
Extreme GIC

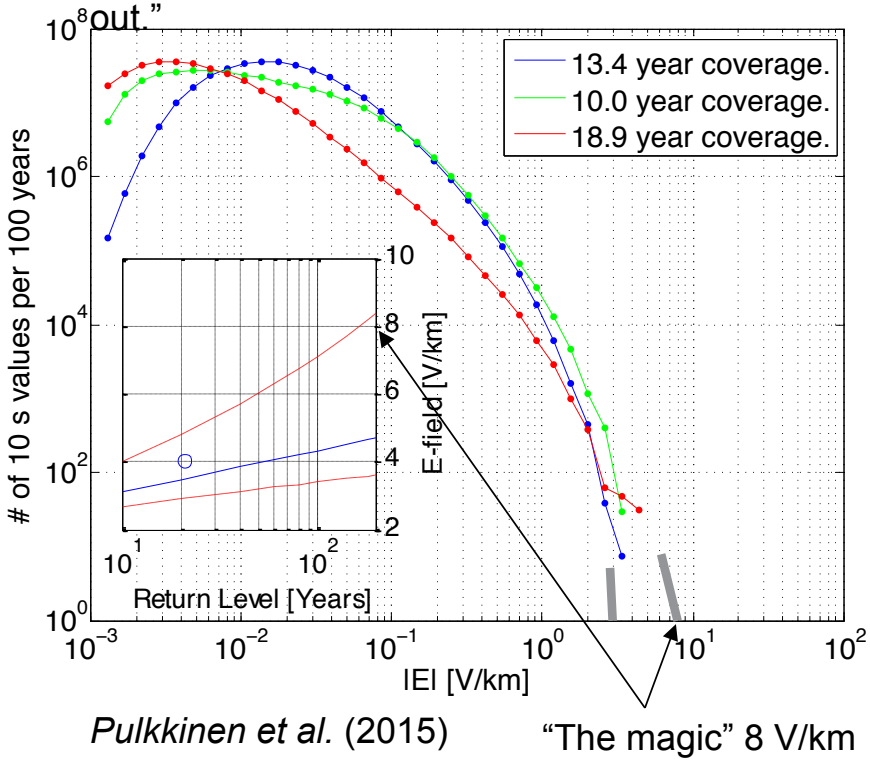
- Current focus of the GIC work is to understand the Carrington storm-like extreme events.
- Extreme events are driving the Federal Energy Regulatory Commission and National Space Weather Action Plan proceedings.

Extreme GIC

While the impact is highly system dependent, I use the following rule of thumb: "0.1 V/km - nobody cares, 1 V/km - hey pay attention, 10 V/km - lights out."

IMAGE magnetometer chain

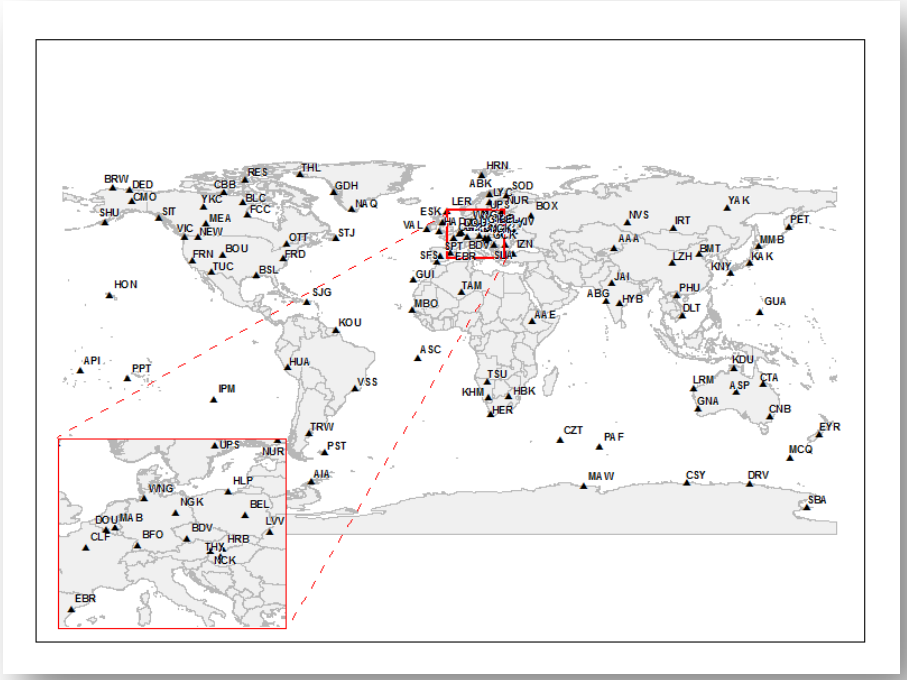




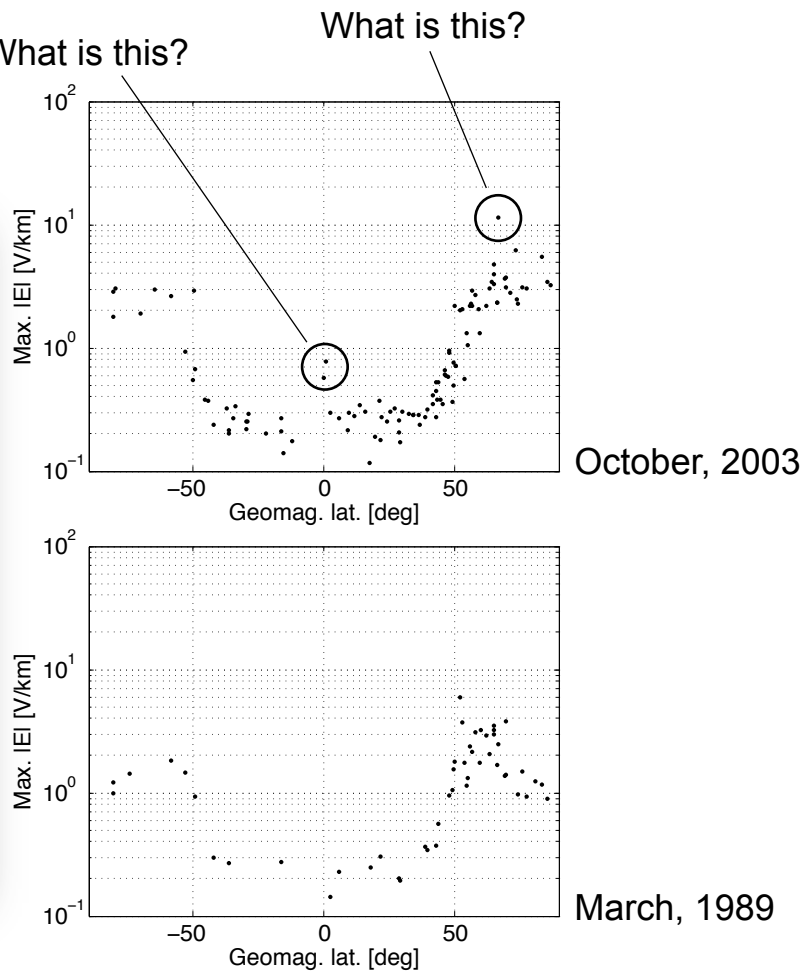
Pulkkinen et al. (2015)

"The magic" 8 V/km

Extreme GIC



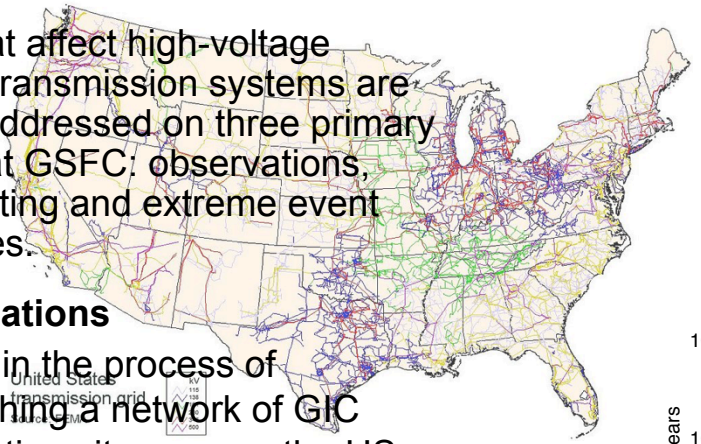
INTERMAGNET network of geophysical observatories



Pulkkinen et al. (2012)

NASA GSFC Geomagnetically Induced Currents (GIC) Activities

GIC that affect high-voltage power transmission systems are being addressed on three primary levels at GSFC: observations, forecasting and extreme event analyses.



Observations

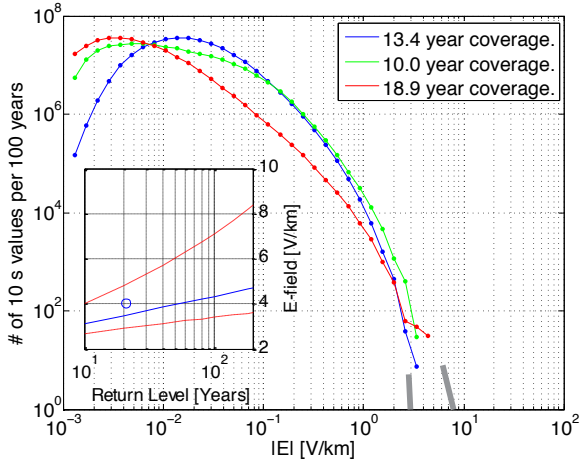
We are in the process of establishing a network of GIC observation sites across the US. The work is carried out in close collaboration with the US power transmission industry.

Forecasting

We have developed state-of-the-art GIC forecasting system called "Solar Shield." Solar Shield was developed further in collaboration with the Department of Homeland Security.

Extreme event analyses

Our extreme GIC event analyses have provided scientific guidance in the NERC/FERC geomagnetic disturbance standards development work.



Conclusions

AGU PUBLICATIONS

Space Weather

REVIEW ARTICLE
10.1002/2016SW001501

Special Section:
NASA's Living With a Star: Geomagnetically Induced Currents

Key Points:
- We provide a broad overview of the status of the GIC field
- We utilize the Applications Readiness Levels (ARL) concept to quantify the maturity of our GIC-related modeling and applications
- This paper is the high-level report of the NASA Living With a Star GIC Working Group findings

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Geomagnetically induced currents: Science, engineering, and applications readiness

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Abstract This paper is the primary deliverable of the very first NASA Living With a Star Institute Working Group, Geomagnetically Induced Currents (GIC) Working Group. The paper provides a broad overview of the current status and future challenges pertaining to the science, engineering, and applications of the GIC problem. Science is understood here as the basic space and Earth sciences research that allows improved understanding and physics-based modeling of the physical processes behind GIC. Engineering, in turn, is understood here as the "impact" aspect of GIC. Applications are understood as the models, tools, and activities that can provide actionable information to entities such as power systems operators for mitigating the effects of GIC and government agencies for managing any potential consequences from GIC impact to critical infrastructure. Applications can be considered the ultimate goal of our GIC work. In assessing the status of the field, we quantify the readiness of various applications in the mitigation context. We use the Applications Readiness Level (ARL) concept to carry out the quantification.

1. Introduction

Geomagnetic disturbances (GMD) cause geomagnetically induced currents (GIC) to flow in long engineered conductor systems such as power grids, pipelines, and railway systems. GIC have become one of the main space weather concerns, and the potential for widespread problems in operating high-voltage power transmission systems during major geomagnetic storms has prompted increasing international policy, science, industry, and public interest in the problem. In the U.S., the latest high-level attention on GIC and power grids is centered around regulatory action initiated by the Federal Energy Regulatory Commission and GIC-related elements of the National Space Weather Strategy and National Space Weather Action Plan [*United States of America Federal Energy Regulatory Commission*, 2013; *National Science and Technology Council*, 2015a; *National Science and Technology Council*, 2015b]. In the UK, GIC are part of the space weather element in the National Risk Registry [*Cabinet Office*, 2015]. In addition, the power transmission industry is quickly elevating awareness to address the GIC issue, acknowledging that the problem pertains to middle and low latitudes as well as high latitudes [e.g., *Gaunt and Coetzee*, 2007; *Liu et al.*, 2009; *Torta et al.*, 2012; *Carter et al.*, 2015]. Consequently, power system operators in nations such as the US, UK, Canada, Finland, Norway, Sweden, China, Japan, Brazil, Namibia, South Africa, and Australia have launched GIC measurement and hazards assessment campaigns to understand and mitigate the possible GIC impact on their systems. The field of GIC has evolved over the past several years from a somewhat separate field of space science research into a full systems science addressing not

Pulkkinen et al. (Space Weather, 2017)

Conclusions

- GIC offers many science, engineering and applications challenges.
- Applied science challenges can boost basic research work.
- There are many urgent open science questions pertaining to GIC → many interesting challenges for YOU!